THE NEXT GENERATION FLEXIBLE GLOBAL ATMOSPHERIC MODEL

Hann-Ming Henry Juang*
Environmental Modeling Center, NCEP, NOAA, Washington, DC

1. INTRODUCTION

The reasons to develop a next generation of the NCEP global atmospheric model are coming from omni-directions. The internal merging of the global model development between weather and climate groups, the possible reduction of the dramatic changes of the model code structure due to the evolution of super computer, the impact of the common model structure, pluggable routines consideration, such as WRF (Weather Research and Forecast) model and ESMF (Earth System Modeling Framework) activities, are the ignition of starting a next generation global model.

This preprint is an attempt to report the current status of the model development. The expectation of the formulation of the model system in the future with current hydrostatic version for hybrid coordinates, the flexible design of the model structure and coding regulation, the preliminary results and the future considerations are given here.

2. THE EQUATION SET FOR THE MODEL

The equation set of the next generation atmospheric model can be from the primitive equation with non-hydrostatic system, however, the assumption of shallow atmosphere as compared to the earth radius should be relaxed. The so-called un-approximated equation system with deep atmosphere similar to the derivation in Staniforth and Wood 2003 is considered as the future target for un-approximated global atmospheric modeling. The three-dimensional momentum equation can be written as

$$\frac{du^*}{dt} = -\frac{1}{\tilde{\rho}}\frac{\partial z}{\partial \zeta}\frac{\partial p}{r\partial \lambda} + \frac{1}{\tilde{\rho}}\frac{\partial p}{\partial \zeta}\frac{\partial z}{r\partial \lambda} + f_s v^* - f_{c^2} w - \frac{u^* w}{r} + F_{u^*}^*$$

$$\frac{dv^*}{dt} = -\frac{1}{\tilde{\rho}}\frac{\partial z}{\partial \zeta}\frac{\partial p}{r\partial \varphi} + \frac{1}{\tilde{\rho}}\frac{\partial p}{\partial \zeta}\frac{\partial z}{r\partial \varphi} - f_s u^* - m^2\frac{s^{*2}}{r}\sin\phi - \frac{v^* w}{r} + F_{v^*}^*$$

$$\frac{dw}{dt} = -\frac{1}{\tilde{\rho}}\frac{\partial p}{\partial \zeta} - g + m^2 f_{c^2} u^* + m^2\frac{s^{*2}}{r} + F_w$$

$$\frac{dz}{dt} = w$$

$$\frac{d\tilde{\rho}}{dt} = -\tilde{\rho}\left[m^2\left(\frac{\partial u^*}{r\partial \lambda} + \frac{\partial v^*}{r\partial \varphi}\right) + \frac{\partial \dot{\zeta}}{\partial \zeta}\right] + \tilde{\rho}\frac{F_\rho}{\rho}$$

where hybrid density is defined as

$$\tilde{\rho} = \rho\frac{\partial z}{\partial \zeta} = \frac{p}{R_d T_m}\frac{\partial z}{\partial \zeta}$$

and vertical velocity can be written as a general form for hybrid type of coordinates, concerning surface pressure, pressure and virtue potential temperature as

$$\dot{\zeta} = \frac{\partial \zeta}{\partial p_{sfc}}\dot{p}_{sfc} + \frac{\partial \zeta}{\partial \theta_m}\dot{\theta}_m + \frac{\partial \zeta}{\partial p}\dot{p}$$

With all above equations, idea gas law and thermodynamics equation, the model equation system is closed. And we have not determined which variable, temperature, potential temperature or entropy to be used for thermodynamics variable for the un-approximated system yet.

As known, the reason why the r and full Coriolis forcing are used instead of earth radius a and horizontal Coriolis only are because of the momentum conservation, nevertheless, the error of the r=a assumption to

*Corresponding author address: Hann-Ming Henry Juang, W/NP2 WWBG Room 204, 5400 Auth Road, Camp Springs, MD 20746. Email: Henry.Juang@noaa.gov

wind speed can be up to several % at very high altitudes. And the including of full Coriolis force should provide a better vertical circulation, especially at lower latitudes. All these consideration may not be necessary for a short-range forecast, but it may influence in long-term integration.

For the backward compatible, we start hydrostatic version of the hybrid coordinate system with virtual temperature as thermodynamic variable. The proximity of the model performance to the operational one should be examine before we step into the above fully non-assumption system. The current hydrostatic system in generalized hybrid coordinate can be written as

$$\frac{du^*}{dt} = \Box \frac{R_d T_m}{\Box(\partial p/\partial \Box)} \Box \left[\frac{\partial(\partial p/\partial \Box)}{a\partial \Box}\right]$$
$$\Box g \frac{\partial z_{sfc}}{a\partial \Box} \Box (\Box_s \Box \Box)\left[\frac{\partial \left\langle R_d T_m / \Box(\partial p/\partial \Box)\right\rangle (\partial p/\partial \Box)}{a\partial \Box}\right] + f_s v^*$$

$$\frac{dv^*}{dt} = \Box \frac{R_d T_m}{\Box(\partial p/\partial \Box)} \Box \left[\frac{\partial(\partial p/\partial \Box)}{a\partial \Box}\right] \Box g \frac{\partial z_{sfc}}{a\partial \Box}$$
$$\Box(\Box_s \Box \Box)\left[\frac{\partial \left\langle R_d T_m / \Box(\partial p/\partial \Box)\right\rangle (\partial p/\partial \Box)}{a\partial \Box}\right] \Box f_s u^* \Box m^2 \frac{s^{*2}}{a} \sin \Box$$

$$\frac{dT_m}{dt} = \Box T_m \frac{m^2}{\Box(\partial p/\partial \Box)}\left[V^* \bullet \Box \Box(\partial p/\partial \Box) \Box \Box\left(\Box \bullet V^*(\partial p/\partial \Box)\right)\right]$$

$$\frac{\partial \left(\frac{\partial p}{\partial \Box}\right)}{\partial t} = \Box m^2\left(V^* \bullet \Box(\partial p/\partial \Box) + (\partial p/\partial \Box)\Box \bullet V^*\right) \Box \frac{\partial \dot{\Box}(\partial p/\partial \Box)}{\partial \Box}$$

where □ is a matrix describes the way to do vertical integration, either by finite difference or finite element methods. The subscribe s indicates the whole column integration, from top of model atmosphere to surface. The vertical advection term for each equation as well as the last term of continuity equation are using invert matrix with related to vertical integration matrix to solve their gradients, but the invert matrix has to satisfy the condition of zero integration in entire vertical column, which is different from the direct invert from matrix □.

We plan to use finite element method as used in Untch and Hortal (2003) for ECMWF. The equation set here is in generalized vertical coordinates, can be used for □, hybrid □-p, and/or □-□.

3. THE DESIGN OF THE FLEXIBLE CODE

The code structure is designed to have possibility to plug in dynamical as well as physics codes. The existed global atmospheric models, such as NCEP, GFDL, NASA, and CCM are studied. The advantage of the existed code is used in the current development. The common model coding regulation is established to have a easily-read coding and for future extension.

The regulation is just a concept with simple rules, such that C language preprocessor is used for code structure options in the model with upper case, and all other in the code are low case. The options with the change of variable values are passing through FORTRAN name-list. The model is coded without pre-defined dimension, so that it can be run with different resolution without recompile.

Any modification due to different platforms, such as thread or multi-parallel routines should be added in with C-preprocessor as an option, so that the model can be easily back to the single processor code without any difficult.

4. CURRENT ACCOMPLISHMENT

The current code with modularized data structure for model predicted variables, constant matrixes, and temporary variables, is finished. The backward compatible to have hydrostatic model dynamics with semi-implicit time scheme is plugged in. The reduced spherical transform developed recently (Juang 2004) is implemented. The two-dimensional decomposition with one-dimensional option is added into the code with C preprocessor. Thus, the code can be run with any number of the processors, including single processor. Furthermore, the current flexible code is not required to recompile the source code for different model resolutions and different number of total processors. Thus, one executive code can be used for all different operational purpose.

Due to the spectral computation, the decomposition of the model cannot be the same as the grid-point model with a fix partial grids with halo areas, where the overlay grid points are used to exchange data among the neighbor processors. The spectral computation needs entire grid to do spectral transform. In order to be able to use multi-processors, the computation are grouped into three directions, and the transpose of the entire model grid into three different decompositions, which are able to do transformation in any given direction in a single process as a multi-process parallel computation for reproducible among different numbers of processors.

Fig. 1 shows the two-dimensional decomposition with two transforms and three transposes in the direction from spectral space to grid-point space, and vice versa. In this case, any two directions without involving computation are sliced depends on total numbers of processors, thus it can use large numbers of processors but it can not be used with prime numbers of processor. However, it is quite easy to add an option to have one-dimensional decomposition as shown in Fig. 2, thus the current code can be used to run any numbers of processor. The reason why it is built in such functionality is because it may perform different in different decomposition, and it can be flexible and cost effective to run optimal number of the processor due to the performance through different decomposition and different numbers of processors.

The same model dynamics and model physics as current operational global model in GFS (global forecast system) are implemented into the current flexible global modeling code. It is the first dynamical code to work with this flexible model structure. The preliminary results show reasonable prediction. Fig. 3 shows an example of the test run from the flexible model using initial condition from T62 L28 analysis on 0000 UTC July 8, 2003. It is 24-hr accumulated rainfall in 10^{-4} m with contour interval of $4x10^{-3}$ m. The rainfall location and patterns are reasonable. It should be compared with the results from the current operational global model. However, it is just an exercise for the new flexible model system, it is not the version for the immediate generation of model. Since the hydrostatic system shown in section 2 can be used for different vertical coordinates, it may be the immediate next generation. The dynamics system and semi-implicit scheme have been all implemented in the flexible model structure. Since the flexible model code is modularized, implementing the new dynamics code was so quick. It is under testing and may be able to present some results in meeting.

5. FUTURE WORKS

The hydrostatic system in generalized hybrid coordinates will be tested with different hybrid vertical coordinates. The hybrid coordinates in the equation system can be used for pure sigma, sigma-pressure, sigma-theta, and sigma-theta-pressure. The definition of hybrid system such as Simmons and Burridge (1981), Konor and Arakawa (1997) and Johnson and Yuan (1998), will be tested first. Several comparisons can be done from all different types of hybrid coordinates. An optimal hybrid coordinate may be able to be selected according to the forecasting scores.

After the hybrid coordinates are selected, the semi-Lagrangian will be considered to add inHowever, the plan may be modified due to the testing results and the operational requirement. Furthermore, it is possible to emerge grid-point computation scheme into the model for higher resolution global modeling.

REFERENCES

Juang, H.-M.H., 2004: A reduced spherical transform for the NCEP seasonal forecast global spectral atmospheric model. *Mon. Wea. Rev.*, 132, 1019-1035.

Konor, C. S., and A. Arakawa, 1997: Designe of an atmospheric model based on a generalized vertical coordinate. *Mon. Wea. Rev.*, 125, 1649-1673.

Simmons, A. J., and D. M. Burridge, 1981: An energy and angular momentum conserving vertical finite difference scheme and hybrid vertical coordinates. *Mon. Wea. Rev.*, 109, 758-766.

Staniforth, A., and N. Wood, 2003: The deep-atmosphere Euler equations in a generalized vertical coordinate. *Mon. Wea. Rev.*, 131, 1931-1938.

Untch, A. and M. Hortal, 2003: A finite-element scheme for the vertical discretization in the semi-Lagragian version of ECMWF forecast model. *ECMWF Technical Memoranda, No. 382*, 27 pp.

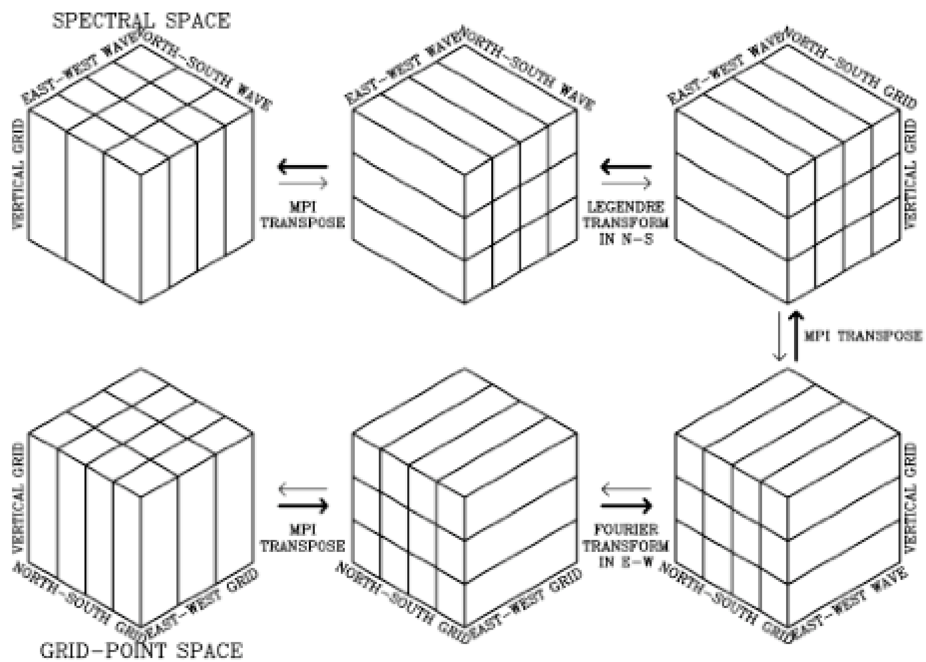

Fig. 1 The schematic diagram of two-dimensional decomposition to transpose between grid-point space and spectral space with the indications of spectral transform. Thick arrows indicated the direction from grid-point space to spectral space, and the thin arrows indicates from spectral space to grid-point space.

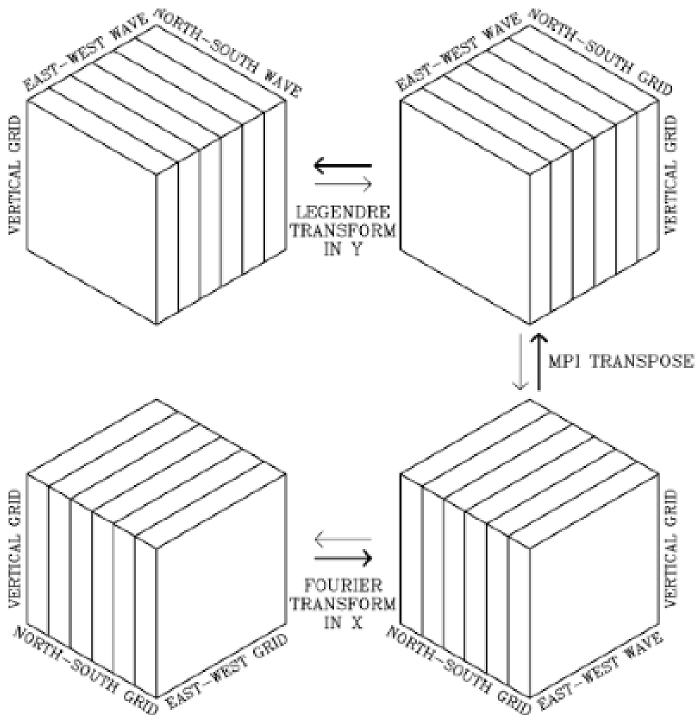

Fig. 2 The same as Fig. 1 except for one-dimensional decomposition.

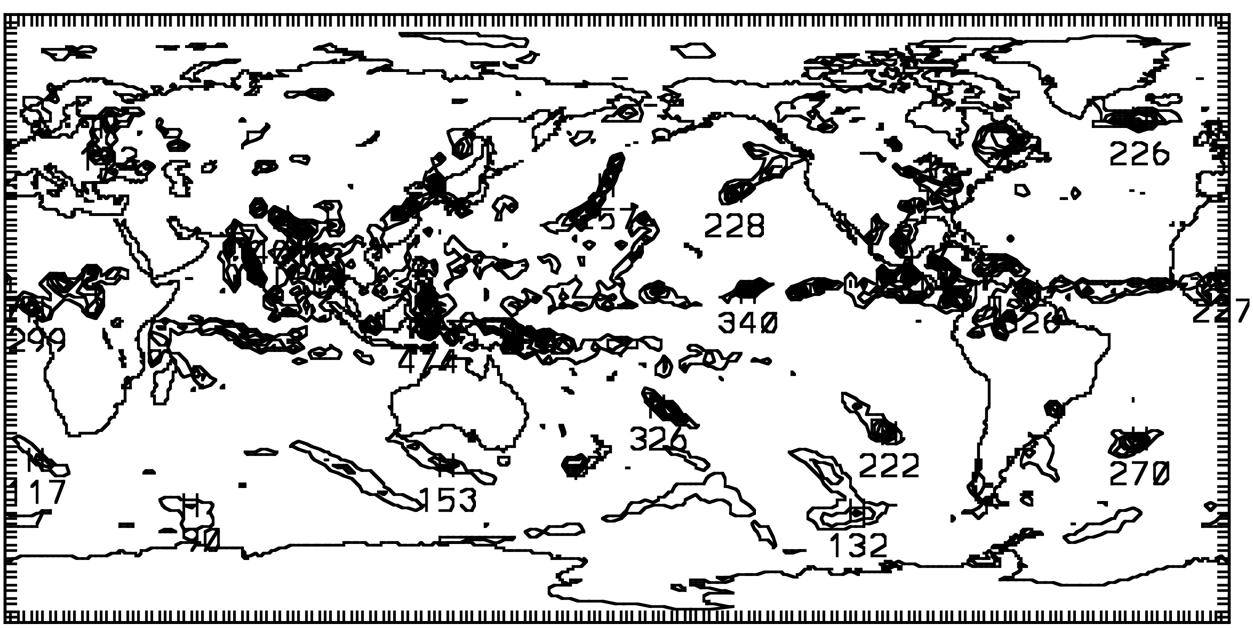

Fig. 3 The 24 hr accumulated rainfall in 10^{-4} m with contour interval of 40×10^{-4} from T62L28 FGM with initial date on 0000 UTC July 8, 2003.